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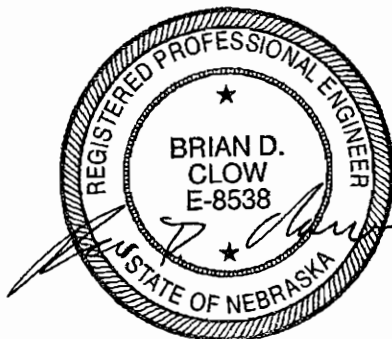
City of Lincoln, Nebraska

STEVENS CREEK BASIN TRUNK SEWER

**TECHNICAL MEMORANDUM NO. 5
PIPE MATERIAL SELECTION**

FINAL

October 2004



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1.0 INTRODUCTION

The Stevens Creek Basin Trunk Sewer will provide sewage service to an area of approximately 53 square miles. Trunk sewer sizes will range from 18 inches in diameter in the upper portions of the basin to possibly 84 inches in diameter in the lower portion of the basin. The materials to be considered for use in the construction of this system should be selected based on historical record, projected service life, maintenance requirements, and cost of manufacturing and installation of the pipe.

In today's environment of close manufacturing cost controls and price competition, it is imperative that the City carefully plan and select the product(s) that can deliver the long-term performance desired for the conveyance of raw sewage and industrial wastewaters. There are several design issues that must be properly addressed, that include but are not limited to:

1. Pipe loads (dead and live).
2. Internal pressure and surge if any.
3. Pipe placement conditions.
4. Trench and embankment conditions and design.
5. Pipe materials.
6. Pipe joints types.
7. Gasket material and loading.
8. Permissible manufacturing variations.
9. Internal corrosion control relating to sulfuric acid corrosion caused by hydrogen sulfide release and the effects of industrial wastewaters especially solvents.
10. External corrosion control relating to corrosive soils and the presence of groundwater.
11. In-plant quality assurance/quality control (QA/QC).

The overall goal is to provide a system (pipe and trench design) that is cost effective and provides the level of service desired. To provide for competition, more than one pipe material and associated trench may be designed. In this case the competitive systems must be designed to provide the same level of service.

2.0 PIPE MATERIAL CONSIDERATIONS

Pipe material selection is based on our understanding of pipe materials that have been used by the City in the past, locally available material, recommendations from City staff, and our firm's history. These include:

1. Reinforced Concrete Pipe (RCP) lined with PVC sheet liner for 36-inch and larger in diameter.
2. Reinforced Concrete Cylinder Pipe (RCCP) lined with PVC sheet liner for 36-inch and larger in diameter.
3. Prestressed Concrete Cylinder Pipe (PCCP), Embedded Cylinder, lined with PVC sheet liner for 36-inch and larger in diameter.
4. Centrifugally Cast Fiberglass Mortar Pipe (CCFMP): 18-inch and larger in diameter.
5. Polyvinyl Chloride (PVC) Pipe: 18-inch to 36-inch in diameter.

2.1 RCP

2.1.1 Introduction

The use of RCP for conveyance of raw sewage has been an industry standard for more than seven decades. RCP is manufactured in several facilities nationwide, several of which are in close proximity to Lincoln. RCP has enjoyed such a following due to its inherent strength, relatively low cost when compared to other products, and lack of ferrous materials in contact with conveyed wastewaters. Originally issued as a tongue and groove joint buttered with mortar, the pipe can now be made in several joint configurations and lined with PVC and other materials. The pipe can be designed to a specific design load termed "D-load pipe," or can be designed on the basis of allowable stresses resulting from bending and shear. The pipeline specifier must choose the best approach to suit the anticipated design conditions.

Concrete pipe designed and manufactured properly can deliver excellent service for the conveyance of domestic and industrial wastewater. However, the converse is also true: that pipe manufactured poorly or based on improper design criteria can lead to poor service life. In today's environment, purchasers of concrete pipe (clients) can expect a quality product in the field if strict adherence to specifications and plant quality control/quality assurance are maintained.

The design and manufacturing of D-load pipe is covered in ASTM C76 for tabular pipe (five D-load classes) and in ASTM C655 for specific D-load pipe. It should be noted that the specifications are somewhat vague on the design-strength of the joint.

The design and manufacturing of direct design pipe is specifically covered in ASTM C361 for tabular pipe(four cover classes and five pressure classes), and in AWWA C302 for specific, direct method design conditions.

The above stated reference to tabular pipe means simply that the referenced specification dictates minimum reinforcement steel requirements that can be expected to deliver the stated design conditions of either D-load, or allowable stresses resulting from earth cover or internal pressure. The tabulated steel therefore represents a historical track of successes supporting long-term performance of the product. The referenced specification is vague on the design-strength of the joint.

2.1.2 Pipe Barrel

RCP is a high-density, wet-cast pipe generally meeting the requirements of American Society for Testing and Materials (ASTM), or American Water Works Association (AWWA) specifications. This pipe is designed as a rigid pipe, meaning that it is designed to carry construction, earth, and traffic loads without significant cracking, or deflection of the barrel.

RCP designed in accordance with ASTM C76 or ASTM C655 is termed D-load pipe. Such pipe is designed using the Indirect Method, meaning that the pipe is designed to deliver an agreed upon level of performance at a specified design. Load is expressed in pounds per linear foot per foot of pipe diameter. The measure of performance is the formation of a 0.01-inch crack for a length of 12 inches pursuant to ASTM C497. At this point in the test loading process, the applied load is recorded, divided by the length of the test specimen, to arrive at longitudinal loading (pounds per linear foot), and then divided by the pipe diameter in feet, to arrive at the specified D-load. Pipe designed in accordance with ASTM C361 and AWWA C302 is designed on the basis of limiting stresses (bending and shear) in the steel and concrete and is termed "pipe designed by the Direct Method." Pipe designed by the Direct Method is usually not load tested pursuant to ASTM C497, and can be tailored to deal with specific pipe loading conditions (pipe placement condition, pressure, surge pressure, depth, etc.). When properly applied, either method of pipe design can deliver the degree of performance required to support the specifics for the project.

2.1.3 Pipe Lining

There are generally three types of lining that are used to prevent sulfuric acid attack on the interior of the concrete pipe. This attack is due to sulfides escaping the sewage as hydrogen sulfide gas and then reforming as sulfuric acid through bacterial action in the crown of the pipe. The degree of this problem is dependent on the amount of hydrogen sulfide forming in the sewage flows, the amount of hydrogen sulfide released, and the temperatures necessary to support sulfuric acid formation. With the availability of linings today and their reasonable cost, it is prudent to install linings to protect the pipe material and extend service life.

2.1.3.1 PVC Lining (T-Lock)

PVC lining is physically bonded into the concrete pipe interior with "T" shaped PVC corrugations. The material is named after its bonding mechanism and is known as T-Lock, which is the brand name registered to its manufacturer, Ameron International. This lining is placed into the interior of the form during the manufacture of the pipe and cast into the interior wall of the pipe. The amount of T-Lock placed into the pipe was originally limited to the top 90 degrees of the crown of the pipe to prevent crown erosion. However, due to noted sulfide attack in large, low-flowing sewers, the degree of coverage has gradually increased to where it is now standard practice to provide a T-Lock lining that covers 360 degrees of the interior surface of the sewer pipe. The manufacturer of T-Lock now sells the product in a tube extrusion to cover the entire interior of the pipe. Placing complete coverage allows the manufacturer to more easily strip the interior form from the vertical cast concrete pipe.

The lining in each section of the pipe is welded to the lining in the next joint in the field. This process requires the use of high-quality equipment by well-trained PVC welders to ensure that good seals are obtained. With 360-degree T-Lock, a short (2 inches at most) section of the weld at the bottom of the pipe is left unwelded. This allows any water that gets behind the T-Lock to be drained into the pipe without creating excessive pressure. This is necessary because even the best concrete is not completely watertight. Full-time inspection and PVC weld testing are required with most contractors to obtain high quality PVC lining and are an important part of the construction quality control program.

Advantages claimed for T-Lock lining include:

1. Provides protection of the interior of the pipe from acid attack and crown corrosion throughout the pipe barrel.
2. Most pipe manufacturers have experience in installing this liner at their manufacturing facilities.
3. The cost for the lining system is reasonable.
4. The lining is easily field repairable.
5. PVC liner is the present standard of the industry for sewer liner.

Disadvantages associated with T-Lock lining include:

1. Requires field PVC welding of the lapped joints at each joint of pipe.
2. In a few cases, low quality PVC welding has resulted in acid attack under the liner in warm sluggish sewer systems.
3. High level of inspection of the welds is required.

2.1.3.2 Cured-in-Place Fiberglass Liner (*Insituform* or *AM-Liner*)

This method consists of lining the interior of the pipe by placing a glass-resin-impregnated flexible felt tube inside the pipeline. The tube is fed into the pipe and held against the walls of the pipe using hydrostatic pressure created by filling the lining with cool water. After the felt and liner are placed, the cool water inside the pipe is replaced with heated water, which cures the resin in place and forms a lining between the pipe and its contents. Following the curing of the liner, the water is removed, the ends are cut back, and the new lining can be placed in service.

The linings are placed in lengths up to 700 feet long from access into the top of the pipe and then sections are glass welded together to provide a continuous lining. Thus, there is not a splice at each joint. Therefore, tight joints in the concrete pipe are less critical, because this eventually forms a second fiberglass pipe inside the concrete pipe. At the present time, the cost of installation of this product is prohibitive for new sewers. The current use of this product is for the rehabilitation of existing corroded sewers. One city has reportedly recently adopted this method of lining new pipelines where risk of sulfide attack is substantial.

Advantages claimed for cured-in-place fiberglass liner include:

1. Provides a continuous liner across all the pipe joints without the need for field welding.
2. Field applied after pipe is placed so that there is no need for liner repair of damage during shipping and handling.

Disadvantages associated with cured-in-place fiberglass liner include:

1. Developed as a method to repair damaged or failing sewers and has limited experience with new pipelines.
2. The cost of installing the pipe and then the liner is more expensive than using a factory installed liner material.
3. Lining installation would be accomplished by an independent subcontractor or a follow-up contract which brings into question a single line of responsibility for pipeline quality, if a quality problem were to arise after construction.

2.1.3.3 Sprayed on Protective Coatings

This method includes spraying high build epoxy, two part epoxy, or cementitious epoxy coatings onto the interior surface of the concrete pipe. Sprayed coating systems has been an industry standard used to protect concrete in wastewater treatment plants, manholes, and junction structures. However, their use as a pipe lining has seen limited use due to high application costs, and in some instances poor performance due to either poor substrate conditions, improper application due to the access allowed by the pipe size, and improper

use and application of the coating systems. Due to the costs, application issues, and historical performance these systems are not recommended for lining the pipe barrel and are not further considered.

2.1.4 RCP Pipe Joints

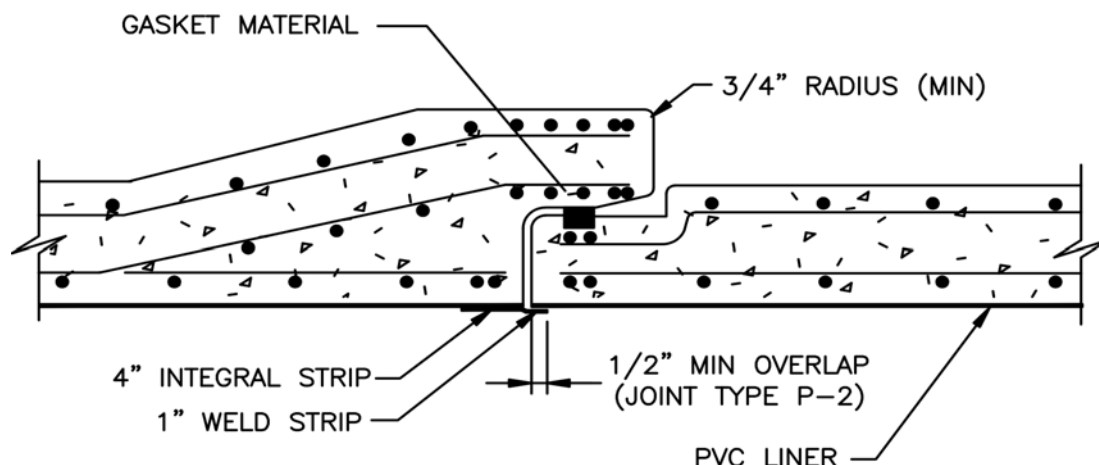
The following types of concrete pipe joints are evaluated for this project:

1. Single gasket concrete joint with projected bell.
2. Double gasket concrete joint with projected bell.
3. Embedded steel joint rings with smooth or projected bell.

Regardless if the joint is projected or smooth, a double row of reinforcing is suggested to extend into both the bell and spigot ends of the pipe. This double row of steel aids in accommodating shear and other forces on the joints. Joints with single cages of steel are not recommended.

2.1.4.1 Single Gasket Concrete Joint

To facilitate a reasonably tight joint for use in gravity pipe to convey raw sewage, a pressure style joint, as used for ASTM C361 low-head pressure pipe, can be applied to the barrel of pipe designed under ASTM C76, ASTM C655, etc. When a single gasket is specified for the joint (as shown below), the joint is deemed not testable. Therefore, to test the joint two inflatable bladders, or temporary bulkheads, one located on each side of the joint are installed and the area between the bladders pressurized. For smaller sewers, the entire installed length may be subjected to an overall leakage-performance installation test.



Advantages claimed for single gasket joints include:

1. Easy to install if properly manufactured.
2. Standard joint used in the concrete pipe industry.
3. Long-term history of success.
4. No ferrous materials in contact with sewage or soils.
5. Competitive cost.

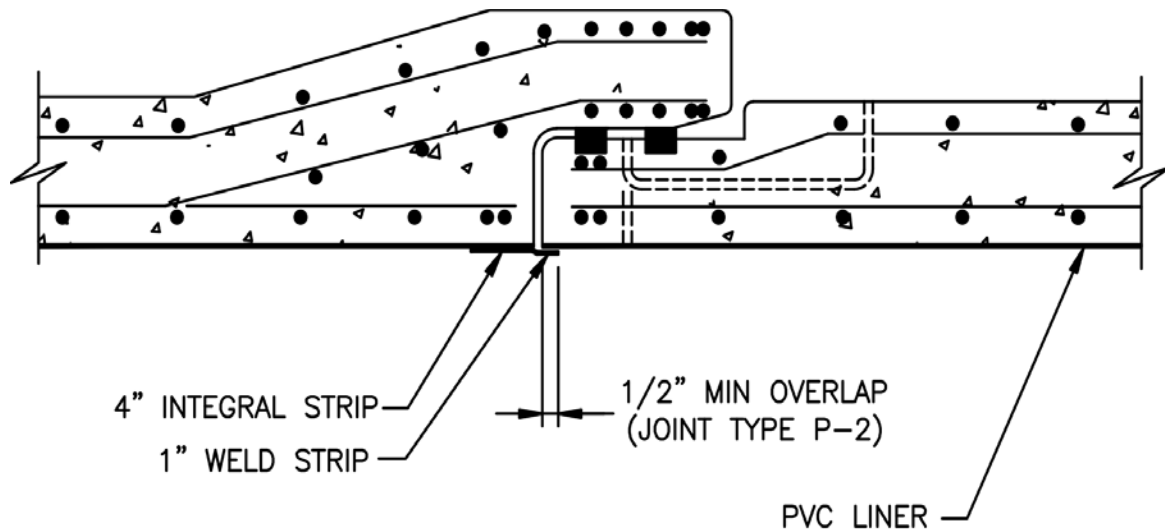
Disadvantages associated with single gasket joints include:

1. Manufacturing joint bells within standard roundness tolerances has been a problem for some manufacturers.
2. Difficult to test each joint.

2.1.4.2 Double Gasket Concrete Joint

This type of joint also contains gaskets as discussed above. However, instead of forming or casting one groove into the pipe spigot, two grooves are constructed. A synthetic gasket is placed in each groove in the spigot and then stabbed into the bell of the adjoining pipe (as shown below). This enables the contractor to rapidly test the joint by inserting water or air into the annular space between the gaskets. Water or air is then pressurized and monitored for a required time period. This allows the contractor to test joints without the need to acquire and position large testing bulkheads and seals. Carollo has specified the use of this joint on large pipelines since 1972. The joint can be provided with the testing tube positioned externally or internally to match the project conditions. Placement of the tube internally allows testing of the gasket seal after backfill on pipe where internal entry is possible.

Proper design and construction of the joint bell and spigot is very important with this design. Having two gaskets on the inserted spigot creates twice as much radial force on the bell as a single gasket would. Additionally, this joint can be longer than the single gasket joint resulting in additional shear and other forces.



Advantages claimed for the double gasket concrete joints include:

1. Easy to install if properly manufactured.
2. Standard of industry.
3. Long-term history of success.
4. No ferrous materials in contact with sewage.
5. Competitive cost where joint test required.

Disadvantages associated with double gasket concrete joint include:

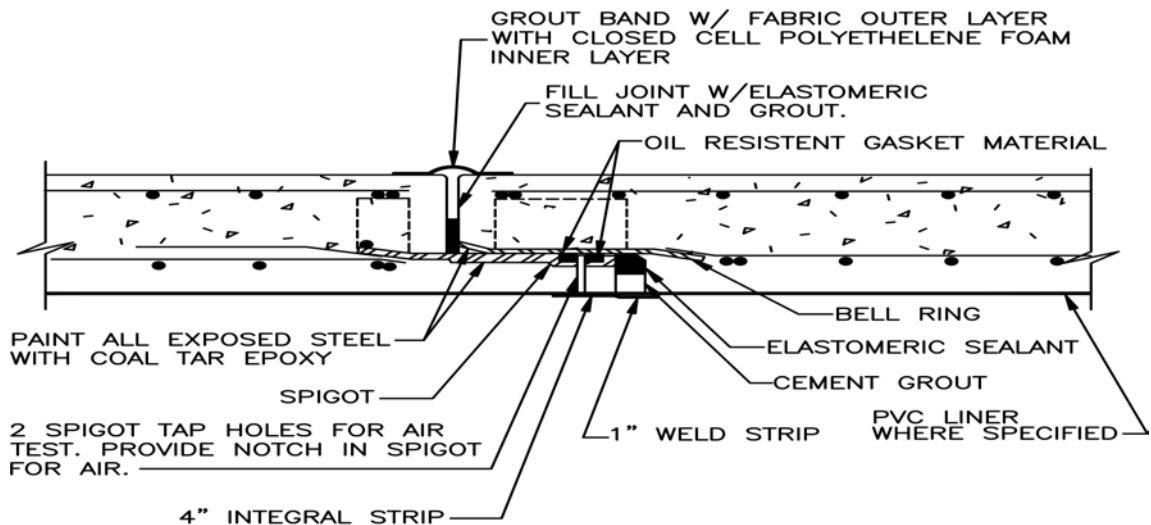
1. Stronger bell is required to address double gasket loads.
2. Two gaskets and two grooves make pipe slightly more expensive to manufacture.
3. Dimensional relationships of the joints are not universally accepted by pipe manufacturers.

2.1.4.3 Steel Joints in Concrete Pipe

A rolled steel bell and spigot ring can be embedded into the end of RCP pipe to form a smooth steel piece for concrete pipe. Often, a steel skirt is welded to the ring and extended into the barrel of the pipe to prevent weeping of water behind the rings. The ring allows a stronger gasket force to be borne by the bell as the spigot is inserted, and generally can be manufactured to a close tolerance. Two gasket grooves are also available to permit a testable joint, as shown below.

When steel rings are used, the joint can be filled with both a urethane caulk and mortar grout to provide some degree of protection of the exposed steel from corrosion from the sewage and surrounding soils. Exposed steel surfaces are coated with a protective

coating such as coal tar epoxy or galvanized to reduce the potential for corrosion to develop.



Advantages claimed for the steel joints include:

1. Provides a stronger bell.
2. Provides a shaped bell and spigot before casting that can be checked for roundness and gasket space tolerances.
3. Manufacturing process can hold tight tolerances.

Disadvantages associated with steel joints include:

1. Joints must be properly secured and placed into the end of pipe barrel to prevent concrete cracking.
2. Buried steel rings susceptible to corrosion.
3. Steel joints must rely on coatings for corrosion protection.
4. Is generally more expensive than a concrete joint.
5. Long-term history for large diameter interceptors is not known.

2.1.5 Pipe Quality Control

2.1.5.1 Inspection of Concrete Pipe Manufacture

To help ensure proper manufacture of concrete pipe, inspection services should be provided at the manufacturing plant for large projects.

2.1.5.2 Inspection of the Installation

To ensure proper placement of the rigid pipe, proper shaping and compaction of the trench bottom are important. To ensure proper support, the bottom of the trench should be rounded to match the pipe to a width of at least 0.4 times the outside diameter before the pipe is placed in the trench. Following pipe placement, the remainder of the bedding should be placed and compacted in lifts to provide additional support and to prevent trench settlement. It follows that the class bedding achieved at the jobsite must be at least equal to or exceed the class bedding used in design.

2.2 RCCP

Reinforced Concrete Cylinder Pipe (RCCP) is similar to RCP pipe discussed above, however a steel cylinder replaces one of the reinforcing steel cages. All materials used in the manufacturing of RCCP, fittings and accessories shall conform to AWWA C300. RCCP is made in sizes up to 120-inch in diameter and is available in lengths up to 24-feet. As with all concrete material this pipe is subject to corrosion by aggressive soils and water. The normal joints for this type of pipe in gravity service consist of smooth bells with steel end rings with a single gasket similar to those described in 2.1.4.3 above. As with RCP it is suggested that RCCP be lined with T-Lock.

Advantages claimed for RCCP include:

1. Provides a stronger bell.
2. Provides a shaped bell and spigot before casting that can be checked for roundness and gasket space tolerances.
3. Manufacturing process can hold tight tolerances.
4. Can be designed for use in deep applications and siphons where internal and external pressures may be greater than normal.
5. Due to its smooth bell and the strength of the steel end ring it has advantages for direct jacking applications.

Disadvantages associated with RCCP include:

1. Joints must be properly secured and placed into the end of pipe barrel to prevent concrete cracking.

2. Buried steel joint rings are susceptible to corrosion.
3. Buried steel joints must rely on coatings for corrosion protection.
4. Is generally more expensive than RCP.

2.3 PCCP

Prestressed Concrete Cylinder Pipe (PCCP) is very similar to RCCP discussed in 2.2 above. The major difference is that the steel cylinder is wrapped with cement coated prestressed wire. PCCP is made using two different procedures. Lined cylinder pipe (LCP) consists of a concrete core inside a steel cylinder that serves as a watertight membrane. The core is then wrapped with prestressed wire and coated with cement rich mortar. LCP is generally available in the 16-inch through 42-inch in diameter sizes. Embedded Cylinder pipe (ECP) consists of a steel cylinder that is fully encased in a concrete core. The core is then wrapped with prestressed wire and coated with a cement rich mortar. ECP is usually available in 36-inch through 144-inch in diameter. All materials used in the manufacturing of PCCP, fittings and accessories shall conform to AWWA C301. PCCP is generally produced in 20 foot lengths. As with all concrete material this pipe is subject to corrosion by aggressive soils and water. The normal joints for this type of pipe in gravity service consist of smooth bells with steel end rings and a single gasket similar to those described in 2.1.4.3 above. As with the other concrete pipes it is suggested that PCCP be lined with T-Lock.

Advantages claimed for PCCP include:

1. Provides a stronger bell.
2. Provides a shaped bell and spigot before casting that can be checked for roundness and gasket space tolerances.
3. Manufacturing process can hold tight tolerances.
4. Can be designed for use in deep applications and siphons where internal and external pressures may be greater than normal.
5. Due to its smooth bell and the strength of the steel end ring it has advantages for direct jacking applications.

Disadvantages associated with PCCP include:

1. Pre-stressing wire can fail due to corrosion resulting in structural compromise of the pipe.
2. Installing PCCP in ground water conditions increases the likely hood of pre-stressing wire failure.

3. Joints must be properly secured and placed into the end of pipe barrel to prevent concrete cracking.
4. Buried steel joint rings are susceptible to corrosion.
5. Buried steel joints must rely on coatings for corrosion protection.
6. Is generally more expensive than RCP.

2.4 CCFMP

Centrifugally Cast Fiberglass Mortar Pipe (CCFMP) sewer pipe is manufactured in several plants throughout the world and is extensively used in Europe. The pipe is manufactured in the United States by HOBAS USA near Houston Texas. Amitech USA located in Zachary, Louisiana also produces FLOWTITE pipe which is similar to CCFMP (HOBAS). FLOWTITE is manufactured using a continuously advancing mandrel process in lieu of centrifugally casting. Both plants manufacture pipe for the entire size range considered per ASTM Standard D3262. These materials are stated to be generally inert to sewage acid attack and soil corrosion. The City has recent experience with the installation of CCFMP on the Salt Valley Trunk Relief Sewer Project.

Fiberglass pipe is designed to function as a flexible pipe, rather than a rigid pipe such as RCP. Flexible pipe design is highly dependent on the surrounding soils and backfill to maintain pipe shape and provide structural load carrying capability of the pipe. Pipe deflections of 3 to 4 percent of the pipe diameter are common in the installed condition unless steps are taken to further limit deflection. Such steps eventually result in higher installed costs. Deflections of 3 percent and below are generally suggested. The installation contractor and the Client's inspection crews need to pay particular attention to the placement and compaction of the soils placed in the pipe zone. Good compaction in these areas will support the side and haunch of the pipe to prevent deflection and will support the soils above the pipe to prevent trench settlements, which would increase the trench loads on the pipe.

This pipe is manufactured with a single grooved spigot on each end of the pipe barrel. The joint is then formed by placing spigots into a structural filament wound sleeve. Joint sealing is accomplished with compression elements inside the sleeve that compress when each spigot is inserted.

Advantages claimed for CCFMP include:

1. Material is inert to most corrosive soils and acids without additional linings or coating.
2. Product is lighter than concrete products and can be installed with lighter equipment.
3. Recent City experience suggests that the product is cost competitive.

Disadvantages associated with CCFMP include:

1. Pipe requires the support of surrounding soils to keep the pipe from deflecting when subject to trench and external loads. It is designed to function as a flexible pipe section.
2. Two gasket sets are required at each joint, which doubles the number of gaskets and the possibility of gasket failure.
3. Pipe has limited United States experience for use in gravity sewer service and hence, long-term effects from soils and sewage may not be fully known.
4. Pipe must be restrained from floating in the presence of groundwater.

2.5 PVC

PVC sewer and water pipe are manufactured in Nebraska by Diamond Plastic Corporation at their Grand Island Plant and many others in the United States and Canada. The PVC pipe for sewer service is manufactured under ASTM D3034 for 4- to 15-inch pipe and ASTM F679 for 18- to 48-inch pipe. The manufacturing specifications for these pipelines allow a substantial percentage of reclaimed plastic material, which results in a weaker pipe material than a pure virgin resin material. Many agencies have obtained a stronger pipe for their sewer service by specifying a water pipe grade material for their sewer pipe service. This can be done by specifying an AWWA C905 pipe, which requires 100 percent virgin resin. We understand that either pipe material will function when properly designed and installed for the project site conditions.

PVC sewers are classified as flexible pipe and depend on the integrity of the pipe trench to maintain the pipe in an acceptably round condition when trench and external loads are applied. Therefore, as with CCFMP, a good quality bedding and backfill and monitoring of the compaction efforts in the field are important. The pipe should be designed to provide the thickness of PVC that is required to withstand the pipe loadings, including traffic, construction, and trench loads. The design should account for possible decrease in strength of the PVC, which will occur with time and when the pipe is subjected to temperatures higher than standard PVC design temperatures. The design engineer should select the appropriate wall thickness and internal diameters for the actual field conditions encountered and the projected wastewater flows. PVC pipe is generally considered to be inert to corrosion.

Advantages claimed for PVC pipe include:

1. Inert material, which provides strong resistance to attack by sewerage components and corrosive soils.
2. Lightweight and can be installed with lightweight equipment.
3. Large manufacturer located in state.
4. Cost competitive with other inert materials.

5. Relatively tight joints if the pipe is not over deflected.

Disadvantages associated with PVC pipe include:

1. Flexible pipe requires a good quality bedding material and bedding placement to prevent pipe from over-deflection.
2. Cost can vary greatly if petroleum product prices vary substantially.
3. Pipe thickness must be selected based on predicted decrease in strength that may occur with age and higher temperatures that could occur while the pipe is in service.
4. Pipe must be restrained from floating in the presence of groundwater.

3.0 CONCLUSIONS

1. City of Lincoln is moving forward with the planning, design and construction of a new wastewater trunk sewer system for the Stevens Creek Basin. Preliminarily, the interceptor will be comprised of 72 or 84-inch diameter piping at the lower end and gradually decrease to 18-inches in diameter at the upper end.
2. Historically, the City has selected PVC lined RCP as the preferred material for large diameter interceptors.
3. Within the last few years, the City has accepted CCFMP as an acceptable substitute material to concrete pipe. The pipe was manufactured by HOBAS Pipe, USA.
4. Recently, the City has accepted the use of a steel style joint ring on RCP used for raw sewage service. However, none has been installed because when bid competitively against CCFMP, the CCFMP has apparently been less expensive.
5. Recently, and as reported by City staff, the City had some quality control/quality assurance problems on a large RCP diameter pipeline project.
6. Carollo's preferred product of choice for use in large diameter sewage interceptors is PVC lined RCP incorporating either a single or double gasket joint (to suit project conditions) and a projected bell.
7. For use in smaller sizes and shallow to mid depth installations, PVC and CCFMP can deliver a satisfactory, long-term service.
8. Wastewater characteristics for the new service area are not known.
9. The relative accuracy of estimating the formation of acid in the soffits of yet to be constructed interceptors is limited.

10. New interceptors, if RCP, RCCP or PCCP, should be installed with a PVC lining system. Other alternative products, if considered, should provide the same level of protection afforded with the use of PVC lining.

4.0 RECOMMENDATIONS

4.1 General

The selection of acceptable pipe materials for a project are based on many factors including but not limited to:

1. Flow conditions including scour and anticipated amount of grit.
2. Corrosion conditions, both internal and external.
3. Flow requirements.
4. Cost effectiveness.
5. Strength and stiffness of pipe including unusual conditions such as railways and highways crossings.
6. River crossings.
7. The presence of groundwater.
8. Points of turbulence such as junction structures and changes in direction and slope.
9. Surrounding soils and geotechnical factors.
10. Product history.
11. Availability of materials.

The following pipe materials are recommended for the Stevens Creek Basin Trunk Sewer project. However, there may be other pipe materials that are not listed that can be used as actual circumstances dictate.

It is assumed that each design firm will select the pipe materials that, in their judgment, meets the specific project requirements for each phase and individual reach of the project.

4.2 Recommended Pipe Materials

4.2.1 RCP

1. Size 36-inch and larger.

2. All pipe shall be provided with 360 degree internal PVC sheet liner, T-Lock, or approved equal.
3. Acceptable joints (at the designers preference) with the appropriate gasket to suit design conditions include:
 - a. Single gasket with projected bell.
 - b. Double gasket with projected bell.
 - c. Single gasket, galvanized steel end rings, external joint diaper, and internal joints grouted.
 - d. Double gasket, galvanized steel end rings, external joint diaper, and internal joints grouted.
4. All trench design loads shall include applicable live loads, plus the calculated soil loads, (including surcharge loads), multiplied by a safety factor of 1.2. (LL + 1.2SL).
5. RCP shall be Class III, Wall B, minimum, or stronger to suit design conditions.
6. Bedding & embedment shall be Type 2 crushed rock or equivalent with a 1.9 bedding factor. (i.e. crushed rock to springline of pipe -minimum).
7. Appropriate geo-textile fabrics shall be used to prevent soil migration into and out of the crushed rock bedding.
8. Selected pipe and manholes shall be tested for leakage after installation.
9. Each joint shall be pressure tested after installation.
10. Inspect manufacturing process and pressure test pipe/joint at manufacturing facility.
11. Perform 3-edge bearing test at manufacturing facility on actual pipe produced for this specific project C76 and C655 only.
12. Perform joint shear test at manufacturing facility on actual pipe produced for specific project.
13. Internal inspection by CCTV and/or visually a minimum 30-days after installation.

4.2.2 RCCP

1. Size 36-inch through 84-inch in diameter.
2. All pipe shall be provided with 360 degree internal PVC sheet liner, T-Lock, or approved equal.
3. Steel end rings shall be galvanized. Internal joints shall be grouted prior to welding the PVC sheet liner. External joints shall include a joint diaper where possible.
4. All trench design loads shall include applicable live loads, plus the calculated soil loads, (including surcharge loads), multiplied by a safety factor of 1.2. (LL + 1.2SL).

5. Bedding & embedment shall be the same as that recommended for RCP.
6. Appropriate geo-textile fabrics shall be used to prevent soil migration into and out of the crushed rock bedding.
7. Selected pipe and manholes shall be tested for leakage after installation.
8. Each joint shall be pressure tested after installation.
9. Inspect manufacturing process and pressure test pipe/joint at manufacturing facility.
10. Perform joint shear test at manufacturing facility on actual pipe produced for specific project.
11. Internal inspection by CCTV and/or visually a minimum 30-days after installation.

4.2.3 PCCP

1. Size 36-inch and larger in diameter.
2. The pipe shall be manufactured using the ECP method.
3. All pipe shall be provided with 360 degree internal PVC sheet liner, T-Lock, or approved equal.
4. Steel end rings shall be galvanized. Internal joints shall be grouted prior to welding the PVC sheet liner. External joints shall include a joint diaper where possible.
5. All trench design loads shall include applicable live loads, plus the calculated soil loads, (including surcharge loads), multiplied by a safety factor of 1.2. (LL + 1.2SL).
6. Bedding & embedment shall be the same as that recommended for RCP.
7. Appropriate geo-textile fabrics shall be used to prevent soil migration into and out of the crushed rock bedding.
8. Selected pipe and manholes shall be tested for leakage after installation.
9. Each joint shall be pressure tested after installation.
10. Inspect manufacturing process and pressure test pipe/joint at manufacturing facility.
11. Perform joint shear test at manufacturing facility on actual pipe produced for specific project.
12. Internal inspection by CCTV and/or visually a minimum 30-days after installation.

4.2.4 CCFMP

1. Sizes shall include 18-inch through 84-inch.

2. All pipe shall be manufactured with polyester resin, unless existing conditions such as soil contamination or industrial discharge dictate otherwise.
3. Joints shall be the standard double gasketed sleeve type joint with gasket material to suit conditions.
4. Gasket joint material designed to suit conditions of service.
5. All trench design loads shall include applicable live loads, plus the calculated soil loads, (including surcharge loads), multiplied by a safety factor of 1.2. (LL + 1.2SL).
6. The E' used for design shall be determined based on the E' of the native soil and imported granular backfill, on a case by case basis.
7. CCFMP shall be Class 72, minimum, or stronger to suit design conditions.
8. Deflection lag factor shall be 1.5, minimum.
9. Maximum design deflection shall be 3 percent or less. As determined by in-situ testing performed no sooner than 30 days after installation.
10. Bedding & embedment shall be crushed rock or equivalent from 6-inches below pipe to 12-inches above pipe, minimum.
11. Appropriate geo-textile fabrics shall be used to prevent soil migration into and out of the crushed rock bedding.
12. Selected pipe and manholes shall be tested for leakage after installation.
13. Each joint shall be pressure tested after installation.
14. Inspect manufacturing process and pressure test pipe/joint at manufacturing facility.
15. Internal inspection by CCTV and/or visually a minimum 30-days after installation.

4.2.5 PVC

1. Sizes shall be 18-through 36-inches.
2. PVC Piping shall be in accordance with ASTM F 679.
3. Wall Thickness shall be "T-1", in accordance with ASTM F 679, to suit design conditions.
4. Cell classification shall be 12454-C per ASTM D 1784.
5. Joints shall be the standard bell and spigot push on joint with gasket material to suit conditions in accordance with ASTM F 679.

6. Gasket joint material designed to suit conditions of service.
7. All trench design loads shall include applicable live loads, plus the calculated soil loads, (including surcharge loads), multiplied by a safety factor of 1.2. (LL + 1.2SL).
8. The E' used for design shall be determined based on the E' of the native soil and imported granular backfill, on a case by case basis.
9. Deflection lag factor shall be 1.5, minimum.
10. Maximum design deflection shall be 3 percent or less. As determined by in-situ testing performed no sooner than 30 days after installation.
11. Bedding & embedment shall be crushed rock or equivalent from 6-inches below pipe to 12-inches above pipe, minimum.
12. Appropriate geo-textile fabrics shall be used to prevent soil migration into and out of the crushed rock bedding.
13. Selected pipe and manholes shall be tested for leakage after installation.
14. Each joint shall be pressure tested after installation.
15. Inspect manufacturing process and pressure test pipe/joint at manufacturing facility.
16. Internal inspection by CCTV and/or visually a minimum 30-days after installation.